

A Proof of Concept Experiment: An Earth Observatory on the Moon

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FROM THE MOON:
EARTH SCIENCE FROM A
LUNAR OBSERVATORY

BASIC IDEA

When astronauts land on the Moon, pictures of Earth will be taken.

The Lunar Earth Observatory replaces random photography with a systematic study of Earth in the visible and at other wavelengths, generating a valuable data set for atmospheric/climate scientists.

That is, we get the photographs plus “added value” of a scientific nature.

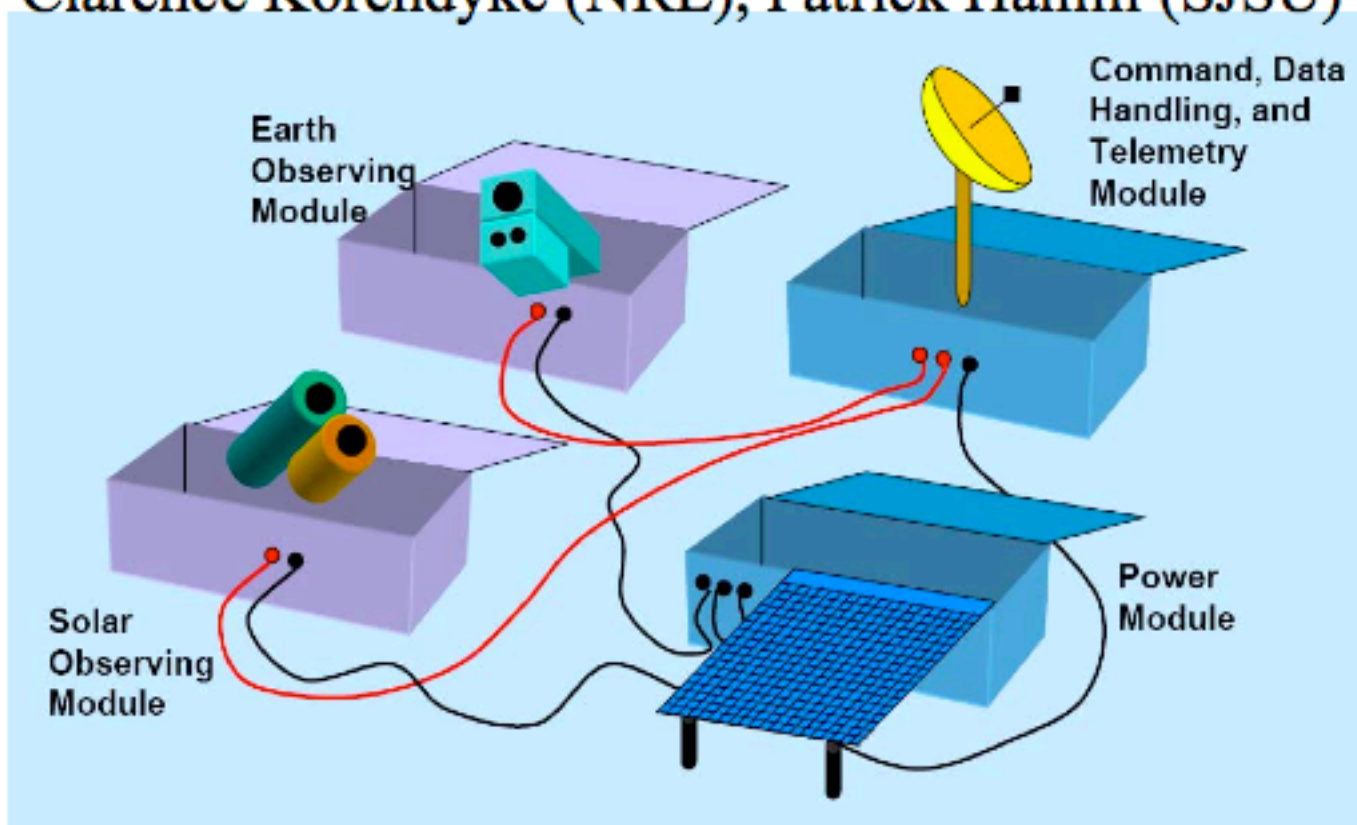
The Lunar Earth Observatory

- An autonomous, simple, lightweight module to observe Earth from the Moon. (“Suitcase science”)
- A camera will take pictures of Earth in the visible. Pictures of Earth will be put on the internet in real time. (Public Outreach as well as monitoring of hurricanes, volcanoes, etc.)
- A small suite of simple instruments will obtain data on column amounts of various gases such as ozone, NO₂, aerosols.
- A radiometer will monitor the IR radiation from Earth.

Janus: Observing the Sun-Earth Connection. A Lunar Mission



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Simultaneous Observations of the Sun and Earth

A simulation showing Earth as seen from Crater Bruce from May 15 to May 30, 2006.

Note that Moon's orbit is tilted relative to Earth's equator by 18.5 to 28.5 degrees depending on time of year. In the following simulation initially we look up at the Antarctic, then we are over the Equator, and finally we look down on the Arctic.



Outline of this talk

- Justification for the experiment
- Feasibility of the experiment
- Design of the experimental equipment
- Education/Public Outreach

JUSTIFICATION

The Moon is an extremely stable platform. The lunar environment is more benign than that of a satellite.

During a lunar month all portions of the Earth are visible, including the polar regions. At any time an entire hemisphere is available for study.

A LEO satellite observes a point on Earth (say Los Angeles) for a few seconds once every 24 hours. A lunar observatory could observe Los Angeles continuously for about 6 hours

A Geostationary satellite observes the same point on Earth continuously, but only that one point.

The psychological impact of seeing Earth from Space should not be underestimated.



This picture changed the paradigm

Feasibility

Factors that affect the feasibility of the observatory are:

- Power during long lunar night
- Telemetry: data rates, on board massaging of data?
- Instrumentation: sturdy, long-lasting, low weight, low power
- Solving the dust problem: Closing apertures when terminator approaches?
- Convincing NASA that the experiment is important

LANDING SITE, RIM OF SHACKELTON CRATER

At Shakedown Crater the Earth is only visible for half the time, as it sinks below the horizon for about 15 days a month. (Not optimal for an Earth observatory but acceptable for a proof of concept experiment)



Temperature Variations

On Surface of Moon the temperature variation is from about 100 K at night to nearly 400 K during the day.

In permanently shadowed regions (at bottom of a crater) the temperature is believed to drop to a permanent 40 to 70 K and even to 30 K if shaded from reflected sunlight.

Should the telescope be placed in a shadowed crater?

The Dust Problem

Dust has been observed at the lunar terminator. It is believed that dust particles of < 0.01 cm to 5 cm in radius are elevated up to 30 cm at the terminator and is due to contracting sunlit areas during sunset. The problem is probably much less serious in permanently shadowed regions.

Properties of the dust:

- Size range = mean diameter of 70 microns, about 20% are smaller than 20 microns
- Dust grains are electrically charged and stick to any surface
- Coarse, sharp dust particles can degrade bearings, seals and other moving parts.
- Did not affect performance of rovers although covered in dust
- Lunar rectroreflectors still “operational” after 50 years

SCIENTIFIC OBJECTIVES

1. Routine Measurements of

- Column Ozone
- Column trace gases such as SO_2 , NO_2 , CO_2 etc.
- Aerosol optical depth
- Cloud coverage, heights, reflectivity, precipitable water

2. Stellar Occultation allows for determination of **profiles** of

- Aerosol extinction
- Ozone concentration
- Other trace gases

SCIENTIFIC OBJECTIVES

3. Visible (photographs)

- Weather prediction, Polar Sea Ice. Hurricane tracking.
- Forest Fires, Early warning of volcanic plumes.
- Industrialization as characterized by lights at night.
- Dust storms, Asian pollution plumes.

4. Radiometer measurements

- Earth brightness, global dimming
- Global energy balance, albedo.
- Regional forcings, Radiative effects of clouds.

SCIENTIFIC OBJECTIVES

5. More speculative objectives

- Calibration of instruments in low Earth orbit satellites
- Monitor the rapidly changing 11 micron radiation that may be a signature of impending earthquakes
- Observation of (say) Los Angeles pollution over a time period of several hours.
- Stellar Occultation to obtain profiles of aerosols, gases (From the Moon the descent of a star through Earth's atmosphere is 8 times slower than from LEO)

INSTRUMENTATION AND DATA OBTAINED

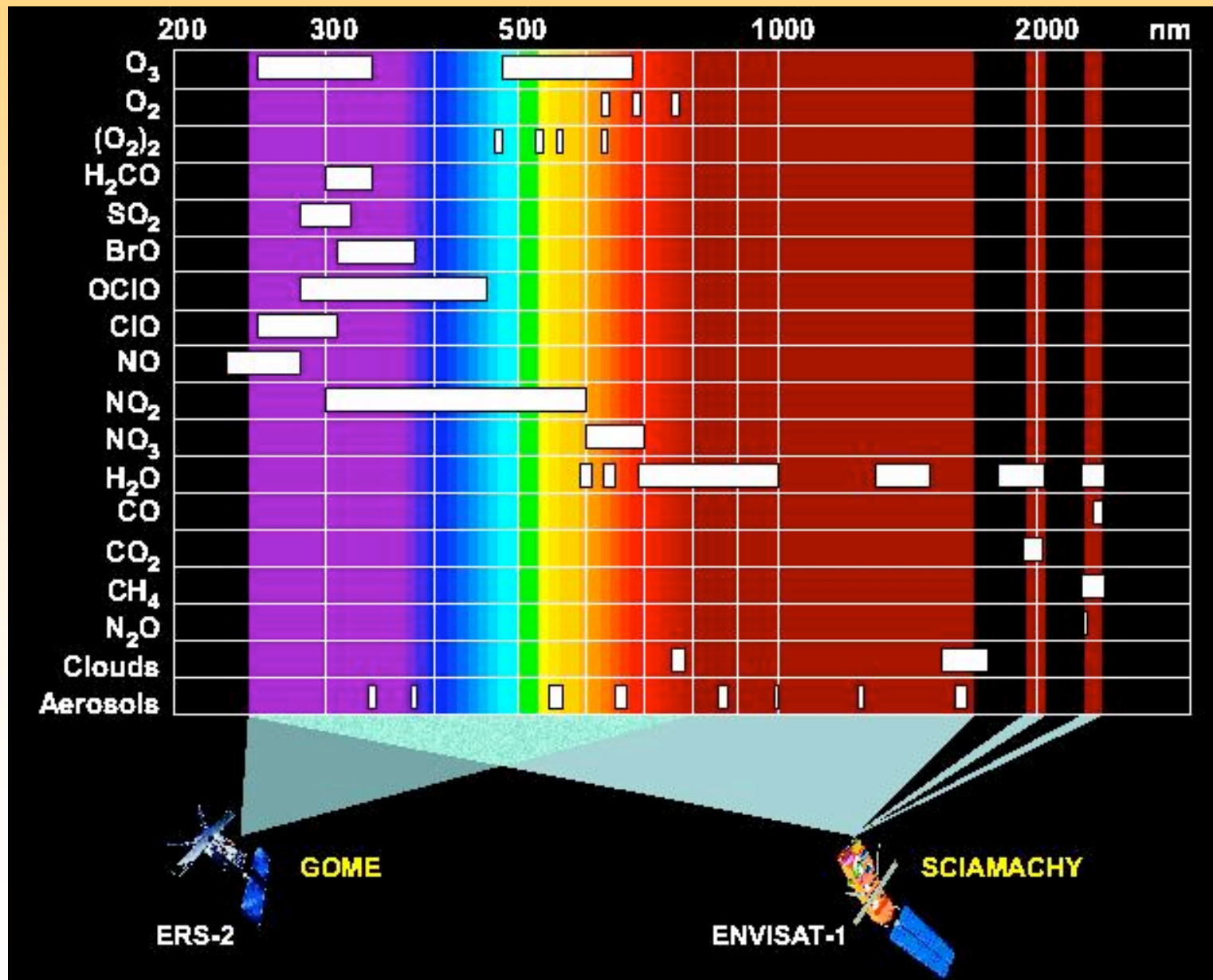
BASIC ELEMENTS OF THE OBSERVATORY

1. Camera for visible pictures of Earth
2. Hyper-spectral Imager
3. Radiometer for IR measurements

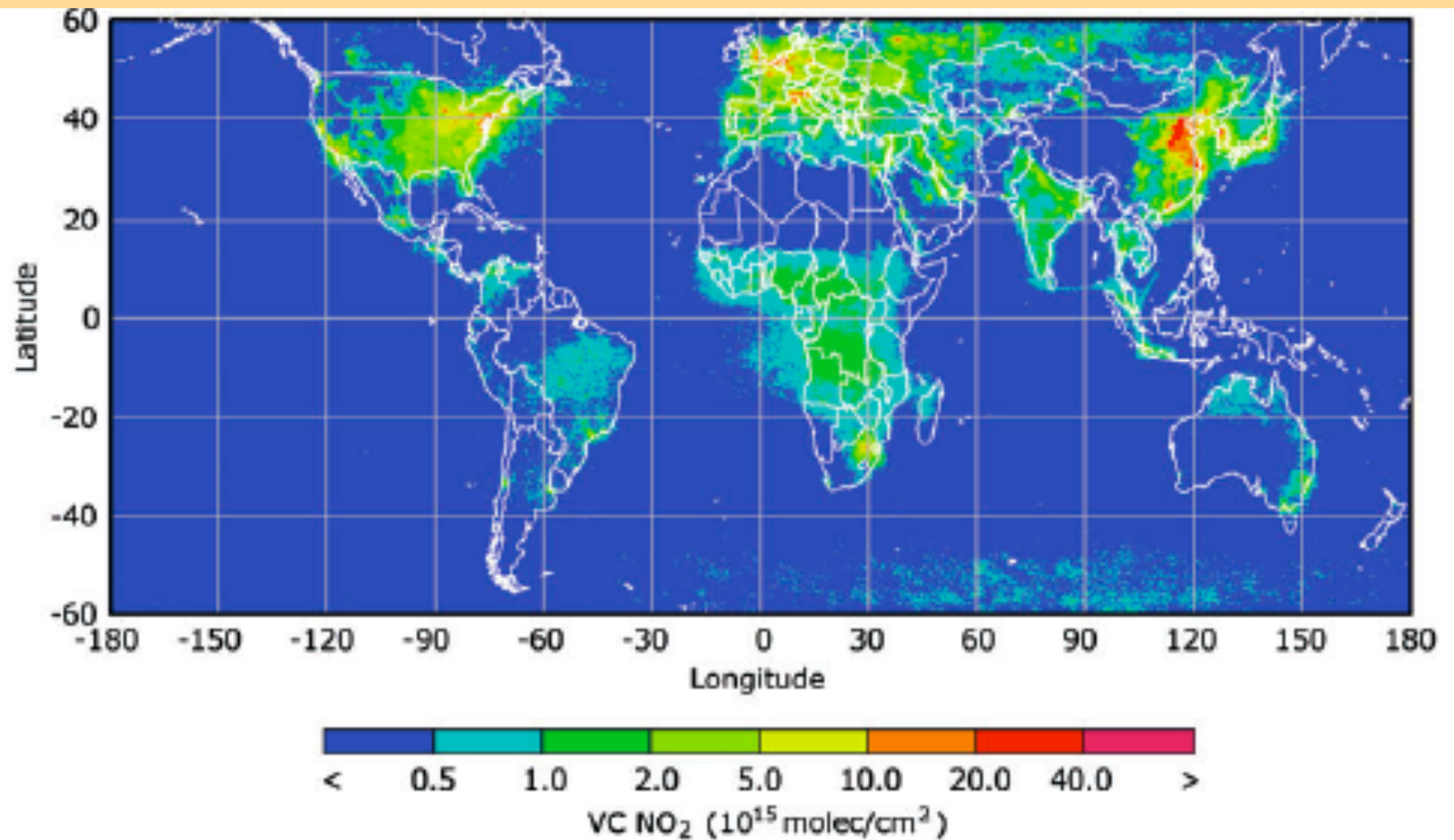
Support elements

1. Steering mechanism for telescope
2. Telemetry package
3. Dust protection device
4. Computer for data compression

Hyperspectral Imagers

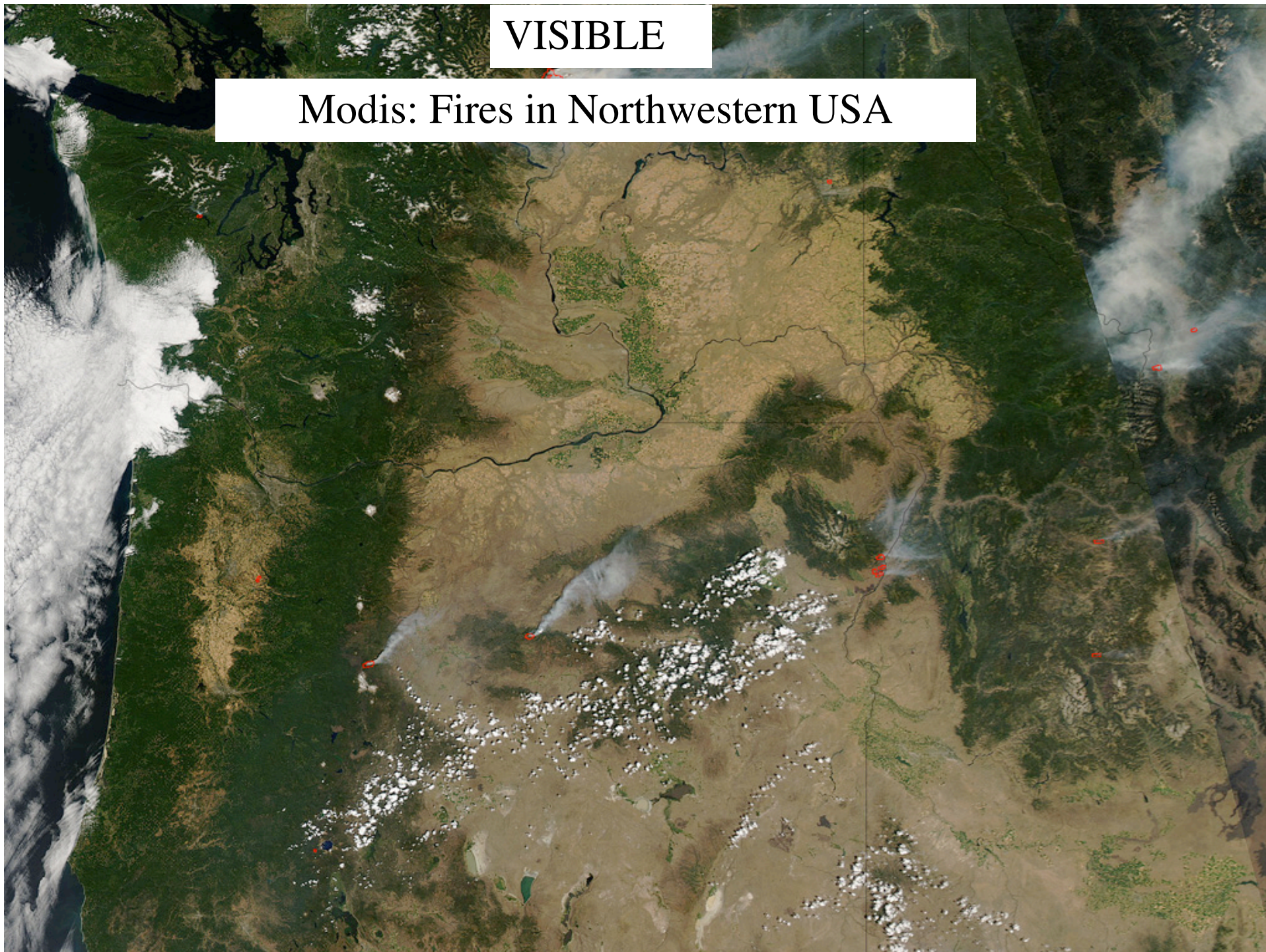


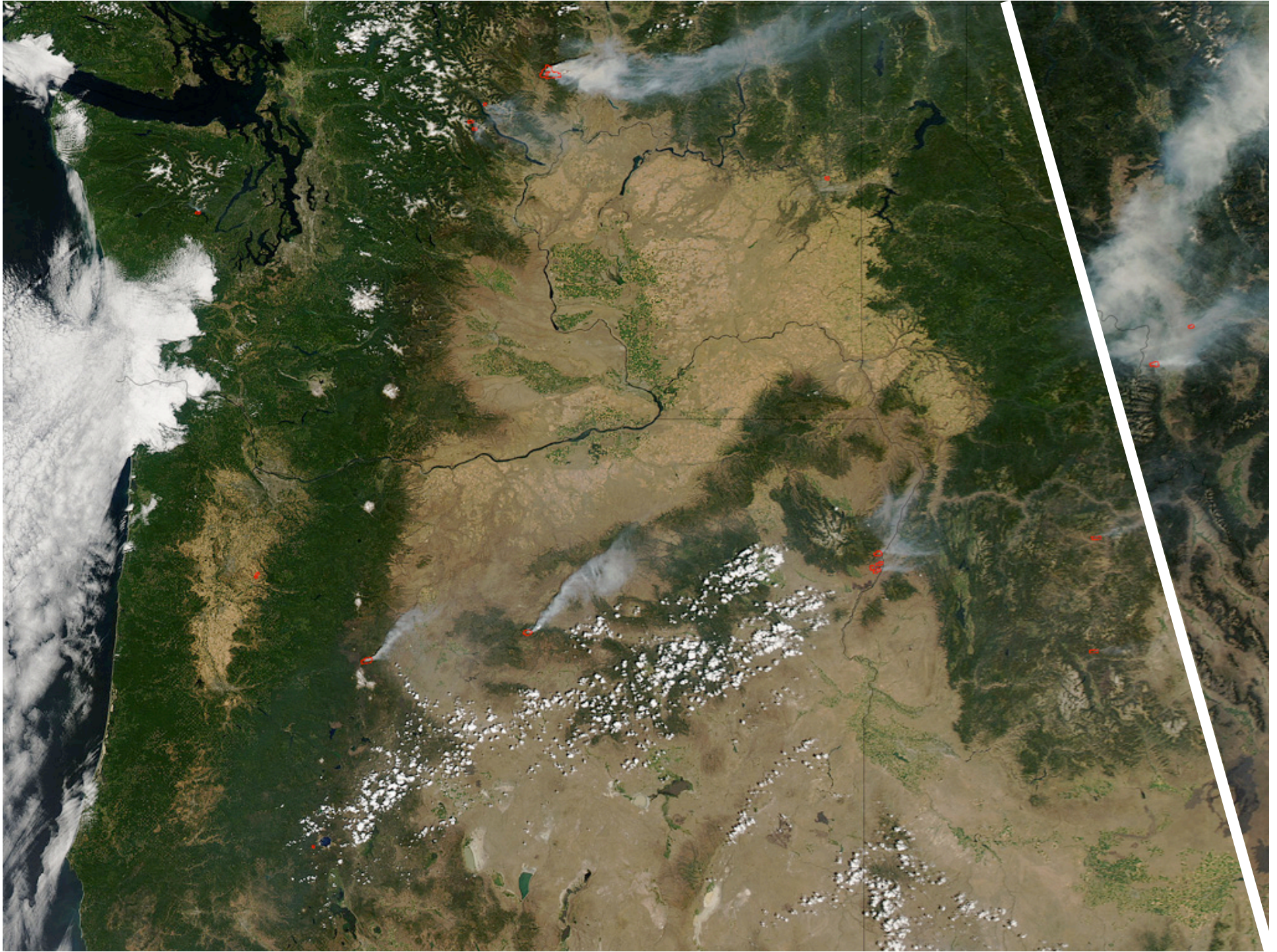
SCIAMACHY Tropospheric NO₂: Dec 2003 - Nov 2004



VISIBLE

Modis: Fires in Northwestern USA



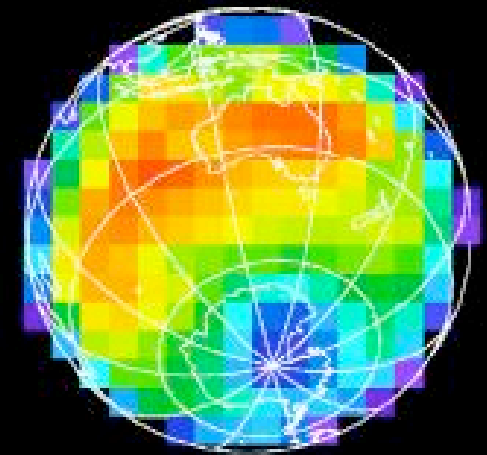


THEMIS

Visible Image



Temperature Image



2001 Mars Odyssey's Thermal Emission Imaging System (THEMIS) acquired these images of the Earth in visible and IR at the same time.

WHY ON THE MOON?

Advantages of being on the Moon:

- a) The Moon is a very stable platform
- b) Temperature variation (day/night) allows us to use cryogen on a long-term basis or do without.
(expendable cryogen lifetime is serious design issue in LEO)
- c) Entire Earth is visible (Phases of Earth introduce interesting opportunities)
- d) A location on Earth can be followed over many hours. (Example: Air pollution episodes in LA or Earthquake precursors)

WHY ON THE MOON?

Advantages of being on the Moon (continued):

- e) Excellent coverage of polar regions (important for ozone hole and PSC studies)
- f) The Moon has no magnetic field and therefore no radiation belts (long exposures in LEO generate “hot pixels” due to impacts with charged particles)
- g) No residual atmosphere (residual oxygen molecule impacts excite faint emissions. Effect of residual atmosphere needs to be subtracted to determine radiation from Earth)
- h) No orbital debris
- i) Thermal environment is stable compared to the rapid changes in temperature in LEO

PROBLEMS & QUESTIONS

- Power when instrument is on “night” side of Moon
- Cooling IR instruments
- Thermal stress as temperature on lunar surface varies from 120 K to 390 K.
- Is stellar occultation feasible?
- Will lunar dust affect the observatory?

Practicalities

- Want 2 km resolution
- Telescope size: Optimal is 30 cm diameter
- Power requirements: < 1kW
- Cost without launch/landing: < 100 million dollars
- Mass involved:
 - Radiometers ~ 25 kg
 - Telescope ~ 30 kg
 - Spectrometer ~ 10 kg
 - Camera ~ 20 kg

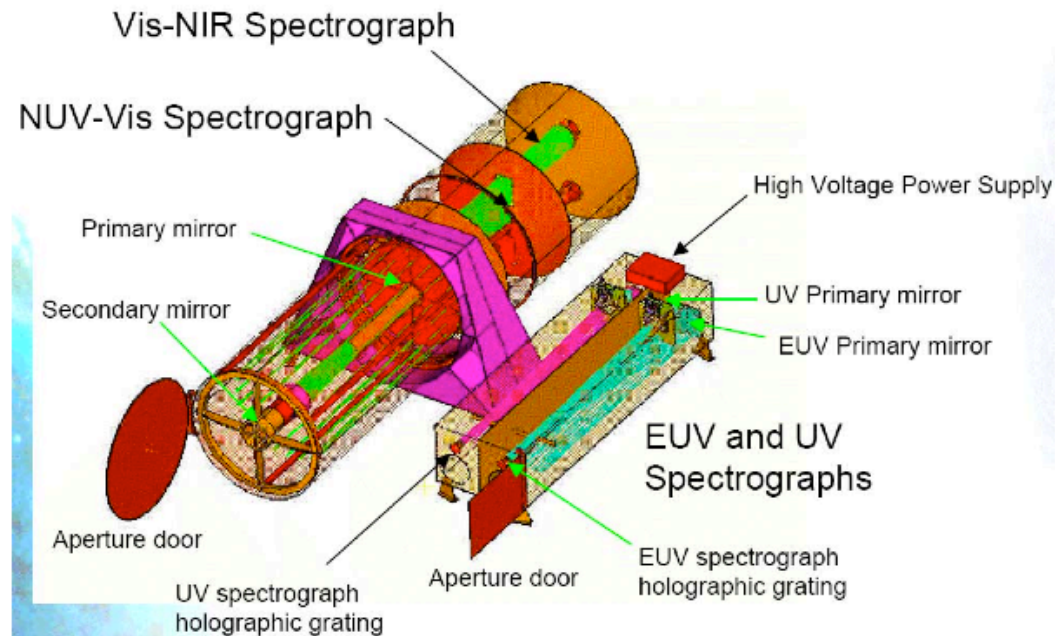
[For Comparison: Mars Observer Camera: Total payload 85 kg, total power 90 Watts, data rate 1.5 Kbps]

Suggestion:

Design a simplified, stand-alone, “suitcase” Lunar Earth Observatory to be placed on the rim of Shackelton Crater by astronauts on the first lunar lander, or on an earlier robotic mission. It would serve as a “proof of concept” experiment. The instruments would be a camera, a hyperspectral imager and an IR radiometer..

Instrument Design

Janus: Earth Viewing Telescope Module



3 spectrometers based on a previous mission design. The larger telescope is for stratosphere and troposphere measurements, while the two smaller telescopes are for airglow and line emissions in the mesosphere. Aperture doors can be closed to protect against dust. For the lunar mission, all aperture sizes are 15 cm.

Janus: Mass, Power, and Cost



Table 2: Nominal Instrument Resource Table

Janus		Mass [kg]	Avg Power [W]		Size	Cost \$M
			Day	Night		
Earth Module						
	Spectrometer	30	15	15	1.2 x 0.5 x 0.3	35
	Structure	10		10		
	Total	40	15	25		
Solar Module						
	Spectrometer	30	30	8	1.2 x 0.5 x 0.3	40
	Coronagraph	15	20	2		
	EUV Monitor	5	5	2		
	Space Environment	15		10		
	Structure	15		10		
	Total	65	55	20		
TC&DH Module						
	Transmitter	8	55	27.5	1.0 x 0.8 x 0.4	4
	CPU & Memory (1200Gb)	15	40	5		
	Structure	10		5		
	Total	33	95	37.5		
Power Module						
	Battery	150			0.7 x 0.3 x 0.3 each	4
	Structure	10				
	Solar Array	10				
	Total	170				
Deployment Pallet						
	Lunar Surface Pallet	20			1.2 x 1.0 x 0.1	0.5
	Structure	10				
	Total	30				
Total Mass and Power						
		338	165	82.5		83.5

A “Proof of Concept” experiment would be much less expensive than JANUS.

It could probably be built for about \$35 million and weigh less than 100 kg.

E/PO

Education: The design of the observatory would be an excellent project for an interdisciplinary group of students (engineering, meteorology, physics) culminating in a proposal to NASA to build and deploy the observatory.

Public Outreach: The visible pictures of Earth from the Moon would be placed on a website (or Google Earth?) on a continuous real-time basis.

Thank you